

R-Parity Breaking via Type II Seesaw, Decaying Gravitino Dark Matter and PAMELA Positron Excess

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(Dated: May 21, 2009)

Abstract

We propose a new class of R-parity violating extension of MSSM with type II seesaw mechanism for neutrino masses where an unstable gravitino is the dark matter of the Universe. It decays predominantly into three leptons final states, thereby providing a natural explanation of the positron excess but no antiproton excess in the PAMELA experiment. The model can explain neutrino masses without invoking any high scale physics while keeping the pre-existing baryon asymmetry of the universe in tact.

I. INTRODUCTION

Recent observation of an excess of positrons in PAMELA experiment [1] in the energy range from 10 to 100 GeV has confirmed similar observations several years ago by the HEAT [2] and AMS [3] experiments. A great deal of discussion is currently under way to understand this excess and its possible implications for physics beyond the standard model. While it is quite possible that this excess is of pure astrophysical origin [4], there is hope that this may be coming from the dark matter in our galaxy. Many models have been proposed to explain this excess in terms of different kinds of dark matter.

Interpretation of the observations in terms of dark matter raises several issues:

- how to explain the lack of any excess in the hadrons?
- how does one get an adequate enough positron production rate to explain the excess?

These issues have been discussed in two broad classes of models for dark matter: (i) stable dark matter pair annihilation [5] or (ii) decaying dark matter [6].

In the first category of models with thermal production of dark matter relic density in the early universe, the dark matter annihilation is constrained by the observed relic density today. If one uses the same value for the annihilation cross section, an additional enhancement is required to understand the observed positron excess for popular dark matter density profiles, e.g. Navarro-Frenk-White (NFW) [7] type. There have been two ways to address this problem: (i) by increasing the local density of dark matter and/or (ii) by introducing new hitherto unobserved light particles [8] that can give rise to the so-called Sommerfeld enhancement of cross sections at lower particle energies.

On the other hand, in the alternative scenario involving decaying dark matter, there is no correlation between the cross section that generates the relic density and the magnitude of positron excess since the latter involves the decay rate which is independent of the physics involved in relic density generation. Therefore the second problem does not arise in this class of models. For this reason, we focus on a decaying dark matter model in this paper.

The issue of lack of hadrons can potentially be a problem in both classes of dark matter models and requires further model building with specific dark matter properties.

The decaying dark matter we consider is an unstable, long lived gravitino which can arise naturally in supergravity models if gravitino is the lightest supersymmetric particle and if the model violates R-parity. The long lifetime of gravitino required for it to be a viable dark matter is automatically satisfied since the gravitino decay involves a combination of the very weak gravitational interactions as well as weak R-parity breaking [9]. Absence of lepton number violation in any observed process to date justifies the second assumption.

Let us start by discussing the familiar R-parity violating models [10], i.e. the minimal supersymmetric standard model (MSSM) with R-parity violating terms in the superpotential of type LLe^c , QLd^c , $u^cd^cd^c$ and LH_u . In these models, one generally expects both leptons as well as hadrons in the final states of gravitino decay. Models of this type have been considered in ref. [11]. If however one kept only the LLe^c term and drop all the others, then, the predominant decay mode of the gravitino will only be to leptons as required to understand the PAMELA data. However, one problem with this scenario is that if the strength of this coupling (usually denoted by λ), is larger than 10^{-7} , this will erase the baryon asymmetry of the universe. While the strength of this magnitude is also what is required for understanding the PAMELA observations, it is too small to explain neutrino masses via loop corrections, without assuming other physics beyond MSSM, e.g. grand unification. Thus if

we want a minimal bottom-up approach to understand the PAMELA observation, while at the same time keeping the baryon asymmetry of the universe untouched and an explanation of neutrino masses with only TeV scale physics, one must seek alternative models. This is what we do in this paper.

We propose a new class of R-parity violating interactions that can arise in extensions of MSSM which does three things using only TeV scale physics: (i) it explains small neutrino masses and mixings via the type II seesaw mechanism [12]; (ii) it keeps the baryon asymmetry of the universe untouched and (iii) it is able to explain the leptophilic nature of the PAMELA observations. as a result of gravitino dark matter decay. We also point out that for a different choice of parameters of the model, consistent with our other requirements, it can explain the recent FERMI observations.

We also point out a novel feature of any decaying dark matter model which decay to photons (even as a subdominant decay mode) that they can be used to map out the dark matter density in the galaxy.

This paper is organized as follows: in sec. II, we present the R-parity violation model and discuss some of its implications; in sec. III, we consider the gravitino as the dark matter and address its decays to show that the model naturally predicts only three leptons as the dominant decay final states; in sec. IV, we present our fit to the PAMELA data; and we conclude in sec. V.

II. NEW R-PARITY VIOLATING MODEL

We extend MSSM by adding a pair of $SU(2)_L$ triplets $\Delta, \bar{\Delta}$ with hypercharge $Y = \pm 2$. The Δ field couples to leptons generating neutrino masses when the triplets acquire small vacuum expectation value (vev). We include only the new R-parity violating interaction that involves the Δ field and no others. In the appendix, we show that this model is radiatively stable.

The superpotential in our model consists of three parts: $W = W_{MSSM} + \delta W + \delta W_{\mathcal{R}}$, where W_{MSSM} is the familiar R-parity conserving MSSM superpotential; δW includes the new R-parity violating terms that involve the Δ and $\bar{\Delta}$ fields and the last term is the \mathcal{R} term. More explicitly,

$$W_{MSSM} = \lambda_u Q^T i\tau_2 H_u u^c + \lambda_d Q^T i\tau_2 H_d d^c + \lambda_l L^T i\tau_2 H_d e^c + \mu H_u H_d, \quad (1)$$

with usual soft terms.

$$\delta W = f L^T i\tau_2 \Delta L + \epsilon_d H_d^T i\tau_2 \Delta H_d + \epsilon_u H_u^T i\tau_2 \bar{\Delta} H_u + \mu_\Delta \text{Tr} (\Delta \bar{\Delta}). \quad (2)$$

The new soft supersymmetry (SUSY) breaking terms associated with δW are

$$\delta \mathcal{L}_S = f_A \tilde{L}^T i\tau_2 \Delta \tilde{L} + \epsilon_{dA} H_d^T i\tau_2 \Delta H_d + \epsilon_{uA} H_u^T i\tau_2 \bar{\Delta} H_u + b_\Delta \text{Tr} (\Delta \bar{\Delta}) + h.c.. \quad (3)$$

Since the terms in δW will be responsible for small neutrino masses, we expect the dimensionless coupling parameters in δW to be very small. Roughly speaking, the corresponding soft SUSY breaking parameters are of the order $\epsilon_{uA} \approx \epsilon_u M_S$, $\epsilon_{dA} \approx \epsilon_d M_S$, with M_S being the SUSY breaking scale.

Let us now discuss the R-parity violating interactions in our model. Note that $H_{u,d}$ have no lepton number whereas Δ has $L = 2$; the above superpotential therefore breaks lepton

number by two units but does not break R-parity. We now add the following interaction which violates R-parity:

$$\delta W_{\mathcal{R}} = a\Delta H_d L. \quad (4)$$

The associated soft breaking terms is given by:

$$\mathcal{L}_{\mathcal{R}} = \rho \tilde{L} \Delta H_d + \text{h.c.} \quad (5)$$

Thus the two R-parity breaking parameters in our model are given by a and ρ . We forbid the R-parity breaking terms of MSSM, i.e. $\lambda L L e^c + \lambda' Q L d^c + \lambda'' u^c d^c d^c + \mu' L H_u$ from appearing in the superpotential. The question of radiative stability of this choice of R-parity breaking is discussed in the Appendix. We will call this type II R-Parity breaking (RPBII) as opposed to the MSSM with R-Parity breaking which we will call type I R-Parity breaking (RPBI). It is easy to see that unlike the RPBI models, RPBII models are quite well hidden in low energy particle physics processes, even for R-Parity breaking couplings of $\mathcal{O}(1)$.

We have found a symmetry which will forbid the $L L e^c$ and the $u^c d^c d^c$ terms of MSSM while allowing the $\Delta L H_d$ term. As far as the $Q L d^c$ term is concerned, once it is set to zero, a very small value for this coupling is induced in higher orders after Δ field takes a vev and it does not affect our results.

As far as gauge coupling unification is concerned, if there is no new physics in the theory above the TeV scale, the couplings do not unify. However, with extra intermediate scale particles, one can restore unification of couplings. We do not address this issue in this paper.

A. Baryon asymmetry and neutrino mass with R-parity violation

As noted in the introduction, the leptophilic nature of the PAMELA data could also be explained by keeping $L L e^c$ terms of MSSM but the coupling strength of this interaction λ must be below 10^{-7} for both baryogenesis protection[13] as well as PAMELA explanation. They will then lead to one loop neutrino masses of order $\lambda^2 m_l / (16\pi^2) \sim 10^{-7}$ eV which are much too small to explain observations.

If one uses grand unified models such as $SO(10)$ to generate neutrino masses via higher dimensional operators such as $\mathbf{16}_m \mathbf{16}_m \mathbf{\bar{16}}_H \mathbf{\bar{16}}_H$, then in this model the R-parity breaking interactions can come from $\lambda \mathbf{16}_m \mathbf{16}_m \mathbf{16}_m \mathbf{16}_H$ type terms after B-L symmetry is broken by the vev of $\tilde{\nu}^c$ field in $\mathbf{16}_H$. One could then make this couplings to be of the right order, i.e. $\lambda \langle \tilde{\nu}^c \rangle / M_{Pl} \sim 10^{-7}$. The problem here is that it also generates $u^c d^c d^c$ type R-P violating terms with similar strength and the model runs into conflict with proton decay. Similar situation happen in the $SU(5)$ model i.e. the interaction $10_m \bar{5}_m \bar{5}_m$ that generates $L L e^c$ type R-P violating term also generates $u^c d^c d^c$ term and therefore will have the same proton decay problem.

The only model where only $L L e^c$ and $Q L d^c$ terms can be generated without generating the $u^c d^c d^c$ term is the model based on the gauge group $SU(2)_L \times SU(2)_R \times SU(4)_c$ where they arise from separate higher dimensional terms- the first two from $FFF^c F^c$ and the last one from $F^c F^c F^c F^c$ where $F = (2, 1, 4)$ and $F^c = (1, 2, \bar{4})$ are the representations of the gauge group that contain fermions.

Our model, on the other hand, is a type II seesaw model with all particle masses in the TeV range. The constraints on the parameters of such models such that they do not erase any pre-existing baryon asymmetry have been discussed in [14]. The discussion for

our model is similar to this paper. A combination of the $f, h_{u,d,l}$ with either $\epsilon_{u,d}$ or a will lead to violation of lepton number, L . Therefore if the strengths of the L -violating couplings are such that the processes caused by them are in equilibrium in the early universe, it will erase any pre-existing baryon asymmetry of the universe. From [14] we see that for neutrino masses in the sub-eV range, the constraints on the triplet vev depend on the mass of the Δ particle and for few hundred GeV mass of Δ , $v_T \leq 10^{-3}$ GeV. We can therefore choose the parameters of the model such that any pre-existing baryon asymmetry is not erased by them.

B. Symmetry breaking and triplet vevs

After electroweak symmetry is broken by the doublet Higgs fields $\langle H_{u,d} \rangle = v_{u,d} \neq 0$, Δ acquires an induced vev, v_Δ . The magnitude of triplet vev's can be estimated by minimizing the potential of the theory to be:

$$\begin{aligned} \langle \Delta \rangle &= \begin{pmatrix} 0 & 0 \\ v_T & 0 \end{pmatrix}, \quad v_T = -\frac{1}{m_0^2} (\epsilon_{dA} v_d^2 + \epsilon_u^* \mu_\Delta v_u^2 + \epsilon_d \mu^* v_u v_d), \\ \langle \bar{\Delta} \rangle &= \begin{pmatrix} 0 & \bar{v}_T \\ 0 & 0 \end{pmatrix}, \quad \bar{v}_T = -\frac{1}{m_0^2} (\epsilon_{uA} v_u^2 + \epsilon_d^* \mu_\Delta v_d^2 + \epsilon_u \mu^* v_u v_d), \end{aligned} \quad (6)$$

where m_0 is the typical SUSY breaking mass and all other parameters are defined in the text. Rough order of magnitude of v_T is $\sim \epsilon_{u,d} v_{wk}^2 / M_S$. If $v_T \leq \text{MeV}$, $\epsilon_{u,d} \leq 10^{-5}$. The triplet vev of an MeV is an input into our model. It could arise from tadpole terms as in the usual type II seesaw models i.e. by minimization of the terms $M_\Delta^2 \Delta^\dagger \Delta + \lambda m_{3/2} \Delta H_u H_u$ by choosing λ of order 10^{-3} .

C. Neutrino mass and constraints from lepton flavor violation

Neutrino masses in our model are given by type II seesaw[12],

$$m_\nu = 2f v_T \approx 0.1 \text{eV}, \quad (7)$$

then implies that if $v_T \leq \text{MeV}$, $f \geq 10^{-7}$. For $v_T \neq 0$, there is a $\nu - \tilde{H}_d$ of magnitude av_T induced which via a seesaw-like formula give an additional contribution to neutrino mass $\sim \frac{(av_T)^2}{M_{SUSY}}$. For the choice of parameters in our model, this contribution to neutrino mass is $\leq 10^{-9}$ eV and is thus negligible.

We now turn to the lepton flavor violation constraints e.g. $\mu \rightarrow 3e$ on the couplings f . In a generic triplet models of this type, $\mu \rightarrow 3e$ decay can arise via the exchange of the doubly charged component of the triplet Δ . Present upper limits on this process restrict the values of the triplet coupling as follows: $f_{11} f_{12} \leq 10^{-6}$. We will keep the f coupling in the range $10^{-7} \leq f \leq 10^{-3}$. We will see later that for natural values of parameters of the model, f will be closer to $10^{-4} - 10^{-3}$.

It is also worth pointing out that in this model after standard model symmetry breaking, the sneutrino field will have a vev; but this vev has a magnitude $\langle \tilde{\nu} \rangle \sim av_T \sim 10^{-11}$ GeV which is much too small to affect any low energy leptonic physics e.g. neutrino mass.

Furthermore, in our model, we do not have a massless Majoron because we have explicit lepton number violation by the terms $\epsilon_{u,d}$. Also since the triplet masses are in the 10^2 GeV range, there is no new contribution to the Z-width.

III. GRAVITINO DECAY AND LIFETIME

To discuss dark matter and its application to PAMELA, we choose gravitino as the lightest supersymmetric particle (LSP) and hence the candidate for dark matter. If the theory conserved R-parity, the gravitino would have been stable. However, since our model has R-parity breaking, it is unstable and as we will see below, it will have a long lifetime so that it can be a viable dark matter of the universe. To estimate the gravitino life time, let us look at its various decay modes and the total width.

The gravitino can have both two and three body decays. First we will show that the two body decay rate is very small for the choice of parameters in the model, making the three body decays dominant. To see this, we note that in this model at the tree level after electroweak symmetry breaking, $\Delta - \tilde{\ell}$ appears, while the other mixings such as $\widetilde{W}^- - \ell^-$ and $\widetilde{Z} - \nu$ are severely suppressed by $\mathcal{O}(\epsilon/a) \ll 1/(16\pi^2)$ comparing with $\Delta - \tilde{\ell}$. The $\Delta - \tilde{\ell}$ mixing gets contributions from both supersymmetric as well as SUSY breaking parts and is given by

$$U_{\tilde{e}\Delta} \simeq \frac{(\rho + a\mu)v_{wk}}{m_{\tilde{e}}^2 - m_{\Delta}^2}. \quad (8)$$

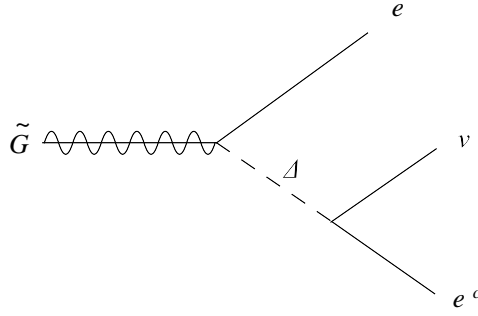


FIG. 1: The Feynman diagram for gravitino decays to three leptons through a triplet Higgs.

The three body tree level decay of the gravitino arises from the Feynman diagram at Fig. 1 and the decay width for $\tilde{G} \rightarrow e^- e^+ \nu_i$ is given by

$$\Gamma_{e^+e^-\nu_i} = \frac{|U_{\tilde{e}\Delta}|^2 |f_{ei}|^2}{192\pi^3} \frac{m_{\tilde{G}}^3}{8M_{\text{pl}}^2} F(x), \quad (9)$$

where $x = m_{\Delta}^2/m_{\tilde{G}}^2$ and the function $F(x)$ is given as $F(x) = (2x-1)(30x^2-66x+37)/12 + (x-1)^3(5x-1)\ln[(x-1)/x]$. For $m_{\Delta} > m_{\tilde{G}}$, the maximum value of $F(x)$ is about 0.04.

For gravitino as the dark matter, we choose its lifetime to be $\sim 10^{26}$ sec, which corresponds to the three lepton decay width $\Gamma \sim 10^{-50} - 10^{-51}$ GeV. For \tilde{G} mass to be ~ 300 GeV, and $m_{\Delta} > m_{\tilde{G}}$, this requires $|U_{\tilde{e}\Delta}f| \sim 10^{-8}$.

Let us now turn to the two body decays of type $\tilde{G} \rightarrow \nu + \gamma, \ell + W, \nu + Z$ etc. These will arise from R-parity violating mixings between $\tilde{\gamma} - \nu, \widetilde{W} - \ell, \widetilde{Z} - \nu$ etc. In our model, these mixings are either absent or severely suppressed by $\mathcal{O}(\epsilon/a) \ll 1/(16\pi^2)$ at tree level. At loop level, they appear in similar way as shown in Fig. 2. To give a typical estimate, we

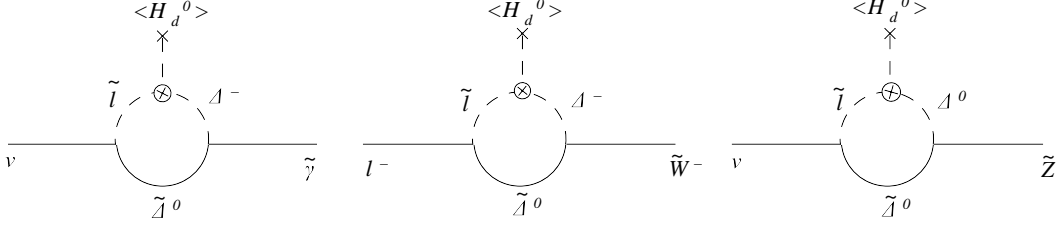


FIG. 2: The one-loop contributions to the R-parity violating mixings between $\tilde{\gamma} - \nu$, $\tilde{W} - \ell$, $\tilde{Z} - \nu$.

find for $\tilde{\gamma} - \nu$

$$U_{\tilde{\gamma}-\nu} \sim \frac{afev_d\mu}{16\pi^2 M_{\tilde{\Delta}} M_{\tilde{\gamma}}}. \quad (10)$$

The two body decay width of the gravitino is given by:

$$\Gamma_{\text{two body}} = \frac{|U_{\tilde{\gamma}-\nu}|^2 m_{\tilde{G}}^3}{128\pi M_{Pl}^2}. \quad (11)$$

The ratio of two to three body decay rates can then be given by:

$$\frac{\Gamma_{\text{two body}}}{\Gamma_{\text{three body}}} = \frac{|U_{\tilde{\gamma}-\nu}|^2 16\pi^2}{|fU_{\tilde{e}\Delta}|^2 4F(m_{\tilde{\Delta}}^2/m_{\tilde{G}}^2)/3}. \quad (12)$$

For $m_{\tilde{\Delta}} \gg m_{\Delta} \simeq m_{\tilde{l}}$, there is a parameter range where the three body decay dominates. As an example, we choose $f \sim 10^{-3}$ and $a \sim 10^{-5}$, we find that $|U_{\nu-\tilde{\gamma}}| \sim 10^{-12} - 10^{-13}$ or so. To get $|fU_{\tilde{e}\Delta}| \simeq 10^{-8}$ then implies that we have to choose $m_{\tilde{e}} \simeq m_{\Delta}$ to about 10% accuracy.

IV. DIFFUSION AND PAMELA OBSERVATIONS

In this section we study the positron signals from the gravitino decay. In this model, the gravitino dominantly decays to three body leptonic states that involve electrons, muons as well as tau's with triplet Higgs mediated. To see this note that the parameter a and ρ in Eq. 4 and 5 have flavor index. For simplicity we could choose this to be along the electron flavor direction. For the case of degenerate neutrinos, then, the gravitino will have the following final states:

$$\tilde{G} \rightarrow e^+(\nu_e e^-, \nu_\mu \mu^-, \nu_\tau \tau^-) \quad (13)$$

In our fit we take all these modes into account. The positron flux from the decay of dark matter in the halo can be obtained by solving the steady propagation equation [15, 16]:

$$\nabla \cdot (K(E, \vec{x}) \nabla f_{e^+}) + \frac{\partial}{\partial E} (b(E, \vec{x}) f_{e^+}) + Q(E, \vec{x}) = 0, \quad (14)$$

where f_{e^+} is the number density of positron per unit energy, $K(E, \vec{x})$ is the diffusion coefficient, $b(E, \vec{x})$ is the rate of energy loss and is assumed to be spatially constant as $b(E) \approx 10^{-16} (E/1\text{GeV})^2 \text{sec}^{-1}$. The source term $Q(E, \vec{x})$ is given by

$$Q(E, \vec{x}) = \frac{\rho(\vec{x})}{m_{\tilde{G}} \tau_{\tilde{G}}} \frac{dN_{e^+}}{dE}, \quad (15)$$

combining the distribution profile of dark matter and the energy spectrum of positron from gravitino decay. The solution of the transport equation at the Solar system can be expressed by the convention [11]

$$f_{e^+}(E) = \frac{1}{m_{\tilde{G}}\tau_{\tilde{G}}} \int_0^{E_{max}} dE' G(E, E') \frac{dN_{e^+}}{dE'}, \quad (16)$$

where the Green's function is well approximately given by

$$G(E, E') \simeq \frac{10^{16}}{E^2} e^{a+b(E^{\delta-1}-E'^{\delta-1})} \theta(E' - E) \text{ cm}^{-3}\text{sec}, \quad (17)$$

where the energy is in units of GeV and we adopt parameters $a = -1.0203$, $b = -1.4493$, $\delta = 0.70$ with assuming the NFW profile and the MED diffusion model [11].

The positron flux from gravitino decay can then be obtained from

$$\Phi_{e^+}^{prim}(E) = \frac{c}{4\pi} f_{e^+}(E) = \frac{c}{4\pi m_{\tilde{G}}\tau_{\tilde{G}}} \int_0^{E_{max}} dE' G(E, E') \frac{dN_{e^+}}{dE'}. \quad (18)$$

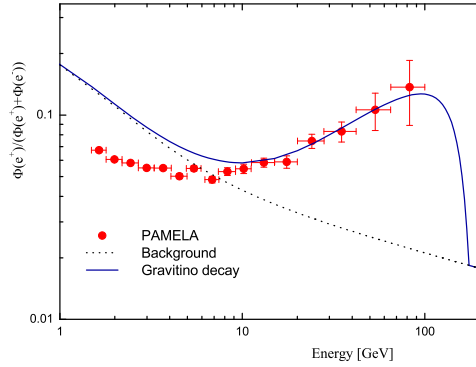


FIG. 3: Fraction of positron flux as a function of energy with the contributions from gravitino decay.

To get the positron flux fraction, one needs to know the background fluxes of primary and secondary electrons and secondary positrons. We use the parametrizations obtained in [16, 17] with the fluxes in units of $(\text{GeV}^{-1} \text{ cm}^{-2} \text{ sec}^{-1} \text{ sr}^{-1})$:

$$\begin{aligned} \Phi_{e^-}^{prim}(E) &= \frac{0.16E^{-1.1}}{1 + 11E^{0.9} + 3.2E^{2.15}}, \\ \Phi_{e^-}^{sec}(E) &= \frac{0.7E^{0.7}}{1 + 110E^{1.5} + 600E^{2.9} + 580E^{4.2}}, \\ \Phi_{e^+}^{sec}(E) &= \frac{4.5E^{0.7}}{1 + 650E^{2.3} + 1500E^{4.2}}, \end{aligned} \quad (19)$$

where E is expressed in units of GeV. The fraction of positron flux is then given by

$$\frac{\Phi_{e^+}^{prim} + \Phi_{e^+}^{sec}}{\Phi_{e^+}^{prim} + \Phi_{e^+}^{sec} + k\Phi_{e^-}^{prim} + \Phi_{e^-}^{sec}}, \quad (20)$$

where $k = 0.88$ is a free parameter used to match the data when no primary source of e^+ flux [16, 18].

For simplicity, we consider the degenerate neutrino mass spectrum, in which case the triplet Higgs mainly couples to lepton pairs with same flavor. We analytically calculate the electron, positron energy spectrums for $\tilde{G} \rightarrow \nu e^+ e^-$ as well as their boosted spectrums from $\mu^+ \mu^- (\tau^+ \tau^-)$ cascade decays. To fit the PAMELA's data, as an example, we take $m_{\tilde{G}} = 350$ GeV, $m_{\Delta} = 700$ GeV, $|fU_{\tilde{\ell}\Delta}| = 2.5 \times 10^{-8}$, therefore the lifetime of gravitino is about 2.1×10^{26} sec and the fitting result is shown in Fig. 3.

Let us now briefly comment on the recent Fermi-LAT observations [19]. The Fermi observation shows a less pronounced $e^- + e^+$ excess above the background in the ATIC energy range of above 100 GeV. We believe that one can get a fit to the Fermi data if we use normal neutrino mass hierarchy and suppress the RPV coupling involving electron superfield. The point is that in this case, the final electrons arise mostly from the decay of the final state muon and tau coupling to the Δ field and therefore have a much softer spectrum. Without suppressing the RPV coupling involving electron superfield, one can choose the parameters as $m_{\tilde{G}} = 3$ TeV, $m_{\Delta} = 2.9$ TeV, $|U_{\tilde{\ell}\Delta}| = 3.5 \times 10^{-9}$, therefore $\tau_{\tilde{G}} = 0.42 \times 10^{26}$ sec. In this case the gravitino decays to leptons and on-shell Δ 's which will mainly produce muons and tauons (then cascade decay to electrons) by choosing the normal neutrino mass hierarchy. The positron fraction and electron-positron spectrum with the contributions from gravitino decay is given in Fig. 4, where $k = 0.72$ is used to normalize the background. We see that for this choice of parameters, both PAMELA and current FERMI data can be fitted well.

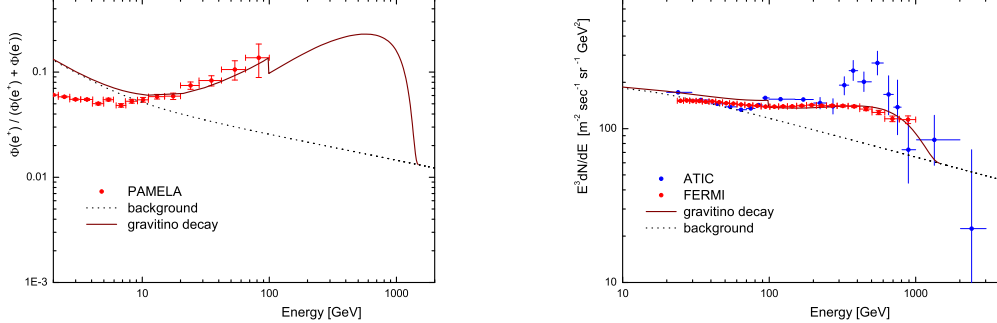


FIG. 4: (left) Fraction of positron flux as a function of energy and (right) the electron-positron spectrum fit after Fermi-LAT data with the contributions from gravitino decay.

V. CONCLUSION

In conclusion, in this brief note we have proposed a particle physics interpretation of PAMELA positron excess in terms of a new class of R-parity violating models (RPBII) which is related to the neutrino mass via type II seesaw mechanism. This provides a natural explanation of why the PAMELA excess is only in positrons and not in hadrons. For the case of normal neutrino mass hierarchy and a different choice of gravitino and Delta field masses, the model can describe also the new FERMI data. This model also provides

an explanation of both small neutrino masses without invoking any physics above the TeV scale while at the same time making sure that any pre-existing baryon asymmetry of the universe is not erased by the R-parity violating interactions. This class of R-parity breaking models turns out to remain very well hidden from low energy experimental probes unlike the MSSM R-Parity breaking models.

An interesting possibility for decaying dark matter with a photon in the final state is the opportunity to measure the dark matter density in the halo using the intensity of the gamma rays from different directions in satellites. We will elaborate on this idea in a future publication.

Acknowledgments

This work was partially supported by the U. S. Department of Energy via grant DE-FG02-93ER-40762. The works of RNM is supported by the NSF grant PHY-0652363. The work of S. N. is partially also supported by this grant and the Maryland Center for Fundamental Physics. Y. Z. acknowledges the hospitality and support from the TQHN group at University of Maryland and a partial support from NSFC grants 10421503 and 10625521.

Appendix: Radiative stability of the vacuum

In this appendix, we address the issue of whether the smallness of ϵ or ϵ_A which characterize the lepton number violating terms are stable under radiative corrections. From the discussion of neutrino mass, we know from Eq. (7) that $\epsilon \approx 10^{-12}/f$, while in order to explain PAMELA anomaly, we demand $a \approx 10^{-8}/f$. To suppress gravitino two-body decay, we need to stabilize the hierarchy to ensure $\epsilon \ll a/(16\pi^2)$.

For this purpose, note first that radiative correction to ϵ is safe because it is a superpotential parameter and is therefore only multiplicatively renormalized due to the non-renormalization theorem of supersymmetry. However the soft term ϵ_A is not multiplicatively renormalized and there is a contribution which is not proportional to itself, as shown in the following figure.

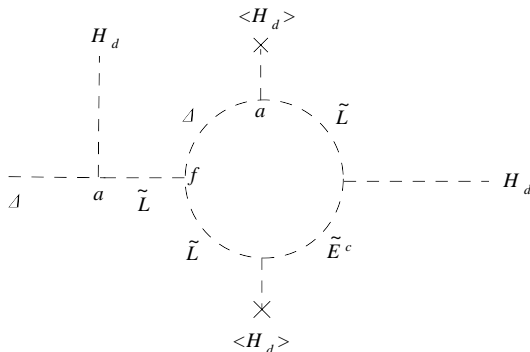


FIG. 5: The radiative contribution to $H_d \Delta H_d$.

We show what the renormalization of ϵ_A would be by a symmetry argument. First, we are considering $H_d \Delta H_d$ soft term, so the radiative correction must be proportional to one

of the soft parameters. Second, $H_d \Delta H_d$ violates lepton number by 2 units, so the radiative correction, if not proportional to itself, must include two $\Delta L = 1$ processes, i.e. $\propto a^2$.

Third, we can extend and restore the Peccei-Quinn (PQ) symmetry by assigning charges to fields and spurion's parameters. In MSSM, the PQ charges are $Y_L = Y_{E^c} = Y_Q = Y_{U^c} = Y_{D^c} = 1$ and $Y_{H_u} = Y_{H_d} = -2$. The PQ symmetry is restored if the parameters also carry charges as $Y_\mu = Y_b = 4$. Now we extend it and set the PQ charges for triplet Higgs as $Y_\Delta = Y_{\bar{\Delta}} = x$. From the $fL\Delta L$ term, we need assign $Y_f = -(x+2)$. In a similar way, $Y_{\mu_\Delta} = -2x$, $Y_a = Y_\rho = 1-x$, $Y_\epsilon = Y_{\epsilon_A} = 4-x$ demanded by the terms $\mu_\Delta \text{Tr}(\Delta \bar{\Delta})$, $L\Delta H_d$ and $H_d \Delta H_d$. From the second comment, to renormalize ϵ_A whose charge is $4-x$, we must need to have two a 's, which totally contribute $2(1-x)$ charge. Therefore it is still short of $x+2$, which is exactly the charge of f^* without other choices.

Therefore, one can conclude that the additive renormalization of the parameter ϵ_A must take the following form

$$\delta \left(\frac{\epsilon_A}{v_{wk}} \right) \propto \frac{1}{16\pi^2} a^2 f^*, \quad (\text{A1})$$

which is $10^{-18}/f \ll \epsilon_A/v_{wk} \approx \epsilon$. So the smallness of ϵ_A is stable under radiative corrections.

We also note that the new R-parity breaking superpotential

$$W_R = aL\Delta H_d \quad (\text{A2})$$

introduces soft R-parity breaking terms of usual MSSM variety from Fig. 6. This term will generate the usual R-parity violating MSSM terms through radiative corrections (except the λ'' term). Their strengths are, however, very weak and do not lead to any observable effects.

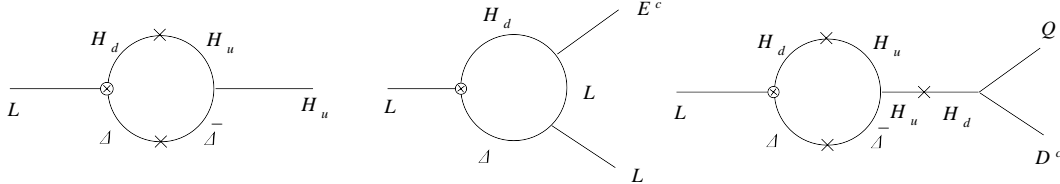


FIG. 6: This diagram generates the $\tilde{L} - H_u$ mixing as well as other soft R-parity breaking terms of MSSM.

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